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THE ACCURACY OF ENVIRONMENTAL TOBACCO SMOKE EXPOSURE MEASURES AMONG ASTHMATIC CHILDREN

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Abstract—This study determined the reliability and validity of parent-reported measures of environmental tobacco smoke (ETS) exposure among 91 asthmatic children. Test–retest reliability assessments were conducted for environmental, biological and parent-reported measures of ETS exposure. All measures except a urine cotinine assay resulted in satisfactory levels of reliability. The parent-reported measures of ETS exposure were compared to the environmental filter measure of nicotine as well as submitted to a construct validity test. Parent-reported home exposure to ETS proved moderately and significantly correlated to the filter measure. Approximately 80% of all hypothetical constructs agreed with the observed relationships for convergent, divergent and discriminant validity. It was concluded that middle class Caucasian parents' reports of their asthmatic child's residential ETS exposure are reliable and valid. These parent-reported measures should be valuable tools for epidemiological investigations and for clinical programs designed to reduce asthmatic children's residential exposure to ETS.

Counseling Environmental tobacco smoke Passive smoking Reliability Validity

INTRODUCTION

Exposure to environmental tobacco smoke (ETS) is associated with morbidity and mortality [1–4]. The Environmental Protection Agency attributed approximately 3000 lung cancer deaths annually to ETS [5]. An estimated 42% of children 5 years and under live in homes with smokers [6]. Children with pulmonary disease are at high risk of complications due to ETS exposure. For instance, asthmatic children living with at least one smoking parent have more severe symptoms than asthmatic children living with nonsmoking parents [7]. These associations make it imperative to investigate the prevalence and nature of ETS exposure in residential settings and to attempt to reduce such exposure in order to reduce consequential morbidity and mortality.

Such investigations require reliable, valid and practical measures. For epidemiological studies, the most practical measures are self-reported.

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Typically, investigators conduct recall-based interviews, provide self-administered questionnaires, or ask respondents to use daily diaries to record estimated levels of exposure. Self-reports have the advantage of low cost and ease of administration [8]. Self-reports of passive smoke exposure can be used to assess the strength of the source, e.g. the number of smokers and the duration of exposure [9]. Questionnaires or other self-reports can provide important information regarding exposure sites, the amount of time the nonsmoker spends in each location [10–14], and information about the physical environments which influence exposure, such as ventilation. No mechanical or electronic recording device can provide these types of data nor can they do so for affordable costs in large scale epidemiology studies. However, reliance on self-reported measures of ETS exposure raises questions of reliability and validity [12, 13]. Memory, ability to discriminate subtle exposures, and reactivity are likely sources of error. False reports are more likely when there are punitive consequences for reports of ETS exposure [13, 15].

Several authors have suggested that more than one measure of exposure, preferably based on different methods of observation, be used to determine the reliability and validity of self-reported results [16–18]. Both biological and environmental measures have been used to estimate ETS exposure or to validate self-reported measures. Biomarkers such as tobacco metabolites obtained from samples of bodily fluids [12] have been reported as the best objective measure of ETS exposure [9, 19].

There are, however, a number of limitations that may affect the quality of ETS biomarker data [20]. The biomarker may not be specific to ETS exposures, can show considerable cross-person variability with similar exposures, and represents only recent exposures. In addition, these markers have not typically been evaluated for sensitivity, specificity, reproducibility, or relation to ETS exposures at environmentally realistic levels.

Sampling errors are an additional concern. Biomarkers are not obtained easily and therefore may not be used as repeated measures or continuously. The timing and frequency of samples may compromise the accuracy of biomarker estimates of ETS exposure. In spite of these limitations, biomarkers are recommended and cotinine has become the most commonly used measure of tobacco exposure [16].

Monitoring the concentrations of air contaminants associated with ETS is an alternative approach for assessing ETS exposure [21]. Air monitoring provides a means of measuring the concentration of ETS in spaces or, when used as a personal monitor, a proxy measure of an individual's exposure over time. Ideally, the contaminants measured should be unique to ETS, in a consistent ratio in air to other contaminants contained in ETS, and easily and accurately measurable at typical environmental concentrations. No single ETS contaminant has been identified as an ideal indicator of ETS exposure. Leaderer and Hammond, however, have developed a passive monitor that has been demonstrated in chamber and field studies to be a valid marker for air concentrations of nicotine [21, 22].

A recent study used this passive monitor worn by subjects to validate a questionnaire and a self-report diary of exposure to ETS [23]. Although large correlations were found, the authors noted that their diary and questionnaire measures needed to be simplified for use with larger samples. They also noted that a personal monitor worn by the subject may be impractical for studies of the effects of passive smoking on children.

The present study explored the reliability and validity of parent-reported ETS exposure among families participating in a clinical trial for reduction of ETS exposure among asthmatic children. The primary objectives of this study were to examine the test–retest reliability of parent-reported ETS exposure of the child, and to determine the validity of parent-reported measures by examining their relationship with a biological and an environmental measure and by construct validity analyses.

METHODS

Sample

Ninety-one families with an asthmatic child 6–17 years exposed to parental smoking were recruited from four asthma clinics in San Diego County. The children averaged 10.6 (SD = 3.2) years: most were male (57%) and most were Anglo (69%). The participating "target" parents (the smoking parent who attended clinic sessions) averaged 38 (SD = 5.8) years; most were female (67%), most were married (72%) and most (87%) had 12–16 years of education. Over 6 months, seven families withdrew from the study due to life events (e.g. divorce).

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Sample sizes varied across analyses depending upon the number of subjects available.

Measures

For the clinical trial, families were randomly assigned to three groups: experimental/counseling to reduce ETS exposure, self-monitoring measurement control, and usual medical treatment control. Measurements were obtained for 2 week intervals prior to intervention and at designated intervals during intervention (2 and 6 months). Parents in the counseling and self-monitoring groups kept a daily dairy of their child's ETS exposure during each 2-week interval. An environmental monitor was placed in all homes during each 2-week interval in the room parents identified as where most exposure occurred. Within the last 24 hours of the 2-week period, each child provided a urine sample for cotinine assay. On the last day of each monitoring period the target parent and the child attended a clinic visit where an interviewer asked questions which provided the primary parent-reported measure of ETS exposure.

Parent-reported measures. Target parents were asked at each interview: "How many cigarettes did you smoke on a typical workday/non-workday at home, during the past week?" They also were asked: "Of those cigarettes, how many was your child exposed to?" Finally, parents were asked: "Please estimate the number of cigarettes to which your child was exposed from others living in the home and those who visited". Answers were reported as number of cigarettes. The first two questions regarding smoking behavior and smoke exposure were asked of the other parent when applicable. The other parent data were used in the computation of a total indoor exposure variable.

During each 2-week measurement period, all smokers placed their cigarette butts in receptacles provided by the project. Receptacles were placed in the same room as the environmental monitor and only cigarettes smoked in that room were to be collected. At the end of 2 weeks the receptacles were collected and the number of butts tallied.

Self-report diaries were assigned only to the counseling and self-monitoring groups (total $n = 59$) during the 2-week intervals. Parents kept daily records of their smoking behavior in the home and the degree of passive smoke exposure to their asthmatic child. As each cigarette was smoked, the parents rated their children's level of cigarette exposure from 0 to 4 ($0 =$ none, $1 = < 1/4$ cigarette, $2 =$ from $1/4$ to $1/2$, $3 = > 3/4$, $4 =$ entire cigarette), indicating the proportion of each cigarette to which the child was exposed. Exposure was defined as being in the same room when a cigarette was smoked. Parents recorded the time, location, and activity corresponding to each cigarette smoked. The diary was used to calculate an average daily number of cigarettes smoked and the children's average daily exposure in the same room as the environmental monitor and in the entire home.

Biological measure. Urine samples were stored frozen at $-20°C$ prior to shipment for analyses (BELRC Laboratory, University of Minnesota). Urine cotinine concentrations were determined by gas chromatography with detection by electron impact mass spectrometry. Urine cotinine concentrations were also standardized to creatinine concentrations to adjust for urine dilution. While reservations have been reported for the reliability of urine cotinine measures [24, 25], this is the currently recommended biological measure of ETS exposure [9, 16, 19].

Environmental measure. Levels of vapor phase nicotine were measured in homes to represent household air concentrations of ETS. Vapor phase nicotine was measured using a passive filter enclosed in a polystyrene cassette [22]. Nicotine passively diffuses to a sodium bisulfate-treated filter and its concentration is determined by gas chromatography. Sampler preparation and analysis was conducted at the John B. Pierce Laboratory (New Haven, CT). The monitor samples at a rate of 24 ml/min and has demonstrated reliability and validity in chamber and field studies [20–22].

Additional measures. The clinic interview included questions relating to asthma symptoms and demographic variables with hypothesized relationships with ETS exposure. The forced expiratory volume in 1 second (FEV_1), a standard pulmonary function test, was also obtained during clinic visits, using spirometers meeting American Thoracic Society recommendations. These measures were used in construct validity analyses.

Analyses

Reliability. Test–retest reliability was performed on all measures using Intraclass correlation [26]. Measures were obtained prior to intervention and at 2 months for both control groups. The experimental group was excluded

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from these analyses because it was expected that their exposure would change due to the intervention which occurred between the two measurement periods.

Validity tests. Two parent-reported ETS exposure measures were compared to a number of alternate measures, which ranged from parent-reported cigarette smoking to the environmental measure of ETS exposure. Validity was judged for each comparison and for the pattern obtained across all comparisons. In addition, the parent-reported cigarette smoking rate was compared to the filter measure as a test of the validity of the reported smoking measures. For each of these tests, Kendall's Tau-b, a non-parametric distribution-free statistic appropriate for partially ordered data, was employed [27]. One-tail tests of significance with $\alpha = 0.05$ were used.

Construct validity hypotheses were selected so that some relationships were positive, some negative, and some null, following Cronbach and Meehl [28]. Validity is inferred if a large proportion of all hypothesized relationships are found in the expected direction. Convergent, divergent and discriminant validity are supported to the extent that positive, negative and null relationships are confirmed. In order to be considered a positive or a negative association the coefficient had to reach or exceed 0.10 or -0.10, regardless of significance. Relationships which were less than ± 0.10 were considered null associations.

Agreements were positive associations ($\geqslant 0.10$) observed for hypothetical positive associations; disagreements were either observed null associations or negative associations for those hypothesized to be positive. Similarly, agreements for hypothesized negative associations were the observed associations which equaled or exceeded -0.10, and null agreements were those associations which fell between ± 0.10. Overall construct validity was tested by counting the number of test results which agreed with hypotheses and by calculating binomial probabilities [29].

RESULTS

Reliability

Table 1 shows the Intraclass correlation coefficients for the test–retest reliability estimates. Parent-reported tobacco use and exposure associations equalled or exceeded 0.60, as did cigarette butt collection. While the air monitor correlation was high ($r_I = 0.72$), the biological marker (urinary cotinine unadjusted for creatinine) correlation was low ($r_I = 0.04$), and could not be considered reliable. The test–retest correlation for the FEV_1 assessment was high ($r_I = 0.96$).

Validity

Table 2 shows the validity correlations for parent-reported smoking and ETS exposure and the collected cigarette butts with the environmental monitor at each of three time points, for all three groups combined. Validity correlations were not included for the urine cotinine biological measure because cotinine concentration (and, hence, cotinine-creatinine ratio) showed low reliability—a necessary condition for validity. Relationships were considered according to measurement categories. The first category concerned parents' self-reported smoking rate compared to the environmental monitor estimate of ETS. Coefficients ranged from 0.18 to 0.43 across measures of cigarette smoking and time and all reached statistical significance ($p < 0.01$). Modest (e.g. 0.25) coefficients were obtained for target parents' reported number of cigarettes smoked on workdays and non-workdays. Workday estimates were more strongly related to the environmental monitor measure than did non-workday estimates. Cigarette butts also were related to the environmental monitor measure of ETS and coefficients tended to be higher than those observed for parent-reported cigarette smoking. Over time the strength of relationships for all measures of

Table 1. Two-month test–retest Intraclass correlation coefficients for selected variables

Variable*	
TP SMKG on typical workday (I)	0.88
TP SMKG on typical nonworkday (I)	0.60
TP SMKG per week (I)	0.86
EXP from TP on typical workday (I)	0.82
EXP from TP on typical nonworkday (I)	0.63
EXP from TP per week (I)	0.76
Average daily EXP (D)	0.84
EXP from all smokers per week (I)	0.81
Cigarette butts	0.67
Urine continine assay	0.04
ETS air monitor	0.72
Pulmonary Function Test (FEV_1)	0.96

*Abbreviations: ETS, environmental tobacco smoke; TP, target parent; SMKG, No. of cigarettes smoked in the home; EXP, No. of cigarettes child is exposed to at home; D, parent-recorded diary; I, parent interview; FEV_1, forced expiratory volume in 1 s.

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Table 2. Validity correlation coefficients for household air nicotine concentrations with parent-reports and collected cigarette butts

Measure‡	Pre-intervention	2 months	6 months
Parents' Smoking Level (Interview)			
TP SMKG on typical workday (I)	0.25**	0.29**	0.39**
	$n = 87$	$n = 85$	$n = 77$
TP SMKG on typical nonworkday (I)	0.19**	0.18**	0.29**
	$n = 88$	$n = 86$	$n = 78$
TP SMKG per week (I)	0.24**	0.24**	0.35**
	$n = 87$	$n = 85$	$n = 77$
Parents' Smoking Level (Diary)†			
Average daily TP SMKG in room with the filter (D)	0.27**	0.43**	0.42**
	$n = 52$	$n = 51$	$n = 46$
Total TP SMKG in room with the filter (for entire measurement period) (D)	0.25**	0.41**	0.41**
	$n = 52$	$n = 51$	$n = 46$
Permanent Product Measure			
Cigarette butts collected for all smokers in room with the filter	0.29**	0.40**	0.47**
	$n = 84$	$n = 81$	$n = 75$
Child's ETS Exposure (Interview)			
EXP from TP on typical workday (I)	0.16*	0.15*	0.25**
	$n = 87$	$n = 86$	$n = 78$
EXP from TP on typical nonworkday (I)	0.07	0.09	0.23**
	$n = 88$	$n = 86$	$n = 78$
EXP from TP per week (I)	0.13*	0.13*	0.26**
	$n = 87$	$n = 86$	$n = 78$
EXP from all smokers per week (I)	0.22**	0.27**	0.35**
	$n = 75$	$n = 79$	$n = 73$
Child's ETS Exposure (Diary)†			
EXP in room with filter (D)	0.30**	0.27**	0.28**
	$n = 52$	$n = 51$	$n = 46$
Total EXP in same room as the filter (for entire measurement period) (D)	0.26**	0.25*	0.28**
	$n = 52$	$n = 51$	$n = 46$
Daily EXP for entire home (D)	0.28**	0.23*	0.31**
	$n = 53$	$n = 51$	$n = 46$

*Denotes significance at the 0.05 level.
**Denotes significance at the 0.01 level.
†Only target parents in the counseling and self-monitoring groups ($n = 59$) recorded diaries. Variable n sizes reflect missing or unusable data.
‡Abbreviations: see Table 1.

smoking tended to increase. These results suggest reasonable reliability for parent-reported smoking in the home.

Table 2 also shows the validity correlations for the children's ETS exposure measures. These coefficients were somewhat lower than those observed for parent-reported cigarette smoking, as might be expected. Nevertheless, most measures exceeded 0.20 and were statistically significant. The pattern of associations paralleled the patterns observed for reported cigarette smoking. Coefficients tended to be larger for workdays than non-workdays, and for summary measures such as all sources inside the home. Diary-based measures of ETS exposure showed higher correlations with the filter than did interview recall measures. Validity estimates tended to increase over time.

Table 3 provides a summary of the degree of agreement for the tested constructs defining the construct validity test for exposure to all sources of ETS in the home at pre-intervention, 2 and 6 months. Convergent validity was estimated by examination of five variables hypothesized to relate positively with reported ETS exposure: child's symptoms, parent's self-reported time spent with child, number of cigarettes smoked at home, environmental monitor and total cigarette butts from the room with the environmental monitor. This resulted in 60–80% agreement across the three time periods. Divergent validity was estimated by use of four variables hypothesized to relate negatively with ETS exposure: child's height, weight, pulmonary function (FEV_1), and parent's level of education. Agreements ranged from 75 to 100% agreement across the three measurement periods. Finally, discriminant validity was estimated by five hypothesized null relationships: parent's age, parent's birth month, whether child receives allergy shots, and both month and day the family entered the study. At each time period,

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80% of these proved null. The binomial probability of the proportion of agreements occurring by chance was statistically significant ($p < 0.05$) for each of the positive, negative and null hypothesized relationships, as well as overall.

DISCUSSION

This study performed a very conservative test of the reliability and validity of the various measures considered. Normally, test–retest reliability assessments are conducted over relatively short periods (e.g. 1 week), especially for dynamic variables which are likely to change over time. By using a 2 month time period between measures, these results incurred the risk of change, thereby decreasing the apparent stability of measures. Thus, even small coefficients may represent relatively reliable measures.

The use of Kendall's Tau-b as a measure of association is more conservative than the Pearson product-moment correlation and as such coefficients tend to be lower. The use of multiple criteria and construct validity tests further makes this test conservative, providing numerous opportunities for identifying associations that do not confirm the hypotheses. Finally, many of these tests were repeated three times during 6 months. Few studies have the opportunity to replicate their findings among numerous validity standards and time points. None have done so for ETS exposure measures.

Reliability

These results are the first to show that parents can reliably report, both by interview and by diary, the number of cigarettes to which their child was exposed. These findings differ from other studies which have found that self-reports cannot provide reliable information about the number of cigarettes to which a person was exposed [12–14, 30–32]. Self-report reliability may have been due to the discrimination of workday and non-workday practices.

Among the reports of tobaco use and exposure, only the smoking behavior and ETS exposure variables for non-workdays were of relatively low reliability. This may have been due to the fact that workdays are more structured for parents and children and that these schedules are more consistent over a 2-month period than those on non-workdays. Future studies should discriminate measures for workdays vs non-workdays and effort should be directed toward enhancing the reliability of self-reported measures of smoking and exposure for non-workdays.

The collection of cigarette butts may be considered a form of self-report, albeit based on a different method of measurement than responses to questions. Because the butts of all cigarettes smoked by any person in the designated room were to be placed in the receptacle, it is possible that the reliability of this measure was affected by actual changes in the number of smokers in the home.

The air monitor data were not as reliable as the self-report data about smoking behavior in the home. This may have been due to reactivity by the subjects, i.e. the smoker may have changed the room in which they smoke the most as a result of the presence of the air monitor. Another possible explanation is that there may have been changes in ventilation between the two sampling periods. This would have affected the measurement of ETS by the environmental air monitor.

The urine cotinine assay did not reach typical standards for reliability. As Curvall *et al.* [33] have suggested, it is important to collect the whole urine void following exposure to get an accurate cotinine measure, and this is difficult to obtain from children. Because the study subjects were asthmatic children, their rates of uptake of

Table 3. Construct validity assessment of parent-reported exposure to all sources of ETS in the home

Hypothesized direction	Pre-intervention	2 months	6 months	Overall
(+)	80% (4/5)	80% (4/5)	60% (3/5)	73% (11/15) 0.05†
(−)	100% (4/4)	75% (3/4)	75% (3/4)	83% (10/12) 0.02†
(0)	80% (4/5)	80% (4/5)	80% (4/5)	80% (12/15) 0.02†
All	86% (12/14) 0.01†	73% (11/14) 0.03†	71% (10/14) 0.07†	79% (33/42) <0.001†

†Probability that the outcome occurred by chance.

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tobacco smoke may have differed considerably between the 2-month period if there were any changes in lung function. Ultimately, this would have affected the bioavailability of cotinine in the body. This is unlikely, given that the subjects' FEV_1 measures remained constant over the 2-month period. Regardless of exact mechanisms, the urine cotinine measure used in this study was not reliable.

Validity

No criterion or "gold standard" is available as a validity measure of ETS exposure. All available validity measures have limitations. The biomarker proved unreliable. The environmental monitor was reliable, but includes known sources of error. Given the relatively small sample sizes available for this study, validity was determined by the magnitude, direction and significance of the observed associations, for all three groups combined. The relationships were examined for each group separately, as well. However, with sample sizes less than 31 for some measurement periods, fewer coefficients reached statistical significance. Those coefficients significantly different from zero confirm relationships seen in the composite sample.

Children are not reliable users of attached air monitors, and for this reason the environmental monitor could not be used in and around their breathing zone. The monitor recorded tobacco smoke when the child was not in the room, and could not record exposure that took place outside of the target room—both sources of type I and II error. Thus, lower correlations were expected for monitor values and ETS exposure measures than for monitor values and smoking rates. This was confirmed.

The pattern of coefficients suggested that the parents' accuracy for reported ETS exposure on workdays was greater than their accuracy for non-workdays, perhaps because the times during which the child and parent were together were more standardized and more limited for workdays than non-workdays. It is also possible that there were more "other" smokers who smoked in the same room as the environmental monitor on non-workdays than workdays. Either possibility would decrease the association between reported exposure and monitor estimates of exposure. These results suggest that future studies should discriminate measures according to work schedules and that effort be directed toward improving the accuracy of non-workday reports of ETS exposure. The overall measure of exposure in the home resulted in modest sized and significant coefficients in relation to the environmental monitor and was judged valid.

The diary measures of ETS exposure proved both reliable and valid, with larger coefficients when related to the filter than the interview measure. Thus, self/child monitoring appeared more accurate than interview recall measures.

Construct validity analysis confirmed the validity of the parent reported measure of the child's exposure to all sources of ETS in the home. The high proportion of agreements between the hypothesized and observed relationships suggests that parent reports of their children's overall exposure to ETS in the home were valid.

The strength of association between the environmental nicotine monitor and each parent-reported measure increased over time. This trend suggests possible increased self-monitoring skills and/or increased concern about ETS exposure. The increased concern is apparent in a modest decrease in smoking rates. This suggests that longer-term investigations should attain satisfactory ETS exposure measures.

The validity of the parent-reported measures of smoking and ETS exposure may have been favorably influenced by the concurrent use of the air monitor and the urine assays. The environmental and biological measures may have conveyed the possibility that parent-report measures were verifiable and thus may have been reactive in the direction of more accurate parent reports. Similar reactivity has been exploited and named the "bogus pipeline", but in this case it was not bogus [34]. Generalizations regarding the reliability and validity of parent-reported measures of ETS exposure should be restricted to similar use of multiple measures where the respondents may be led to believe that their reports are verifiable.

The generalizability of these results also should be restricted to middle class and Anglo families who may be concerned about the health of their child. Until similar measures are employed with samples representing the general population, the degree to which these parent-reported measures are accurate for more broadly defined or special (e.g. minority) populations is uncertain. In the interim, these measures hold promise for clinical control of ETS exposure among children with pulmonary

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disease who live with a parent who smokes cigarettes.

In conclusion, parent reports can be both reliable and valid measures of smoking behavior and ETS exposure. Self-reported measures are the only practical tools available to obtain information about room ventilation, number of smokers to which a passive smoker is exposed, and the activities that smokers or the exposed individuals perform when exposure takes place. These details may be critical for analyses of ETS exposure and for designing interventions to control ETS exposure. Recent analyses of self-reported parent smoking and child's ETS exposure patterns in the home have shown that the locations, activities, and times in which each occur most reliably are not identical. This suggests that measures and interventions with respect to children's ETS exposure are improved by direct assessment of self-reported exposure patterns [35]. Parent-reported measures are also the most practical for use in large sample epidemiological studies of the determinants or health consequences of ETS exposure. Thus, while these results warrant replication, they suggest that middle class Anglo parents' reported estimates of their ill children's exposure to ETS are sufficiently reliable and valid for clinical research and preventive medicine purposes.

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